Xenon plus additives in the Energetiq EQ-10

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ABSTRACT

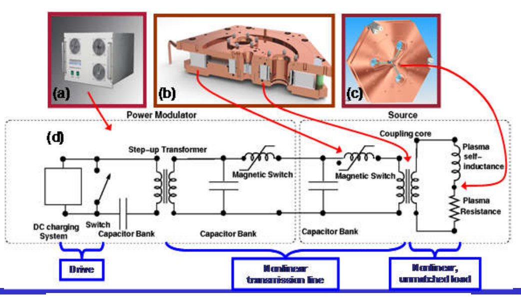
A search of the older EUV literature reveals various attempts to improve the performance of Xenon discharge EUV sources by the addition of other gasses[1,2,3,4]. Significant (up 40%) increased EUV power was reported using helium dilution to give ~ 15% xenon partial pressure, compared to operation in pure Xenon.

Early in the development of the EQ-10 Electrodeless Z-pinch source, we experimented briefly with helium injection. Recently we have revived the idea, to address an un-related problem. When the EQ-10 is used in an application requiring a arge source etendue, the nature of the electrode-less discharge causes a plasma plume to exit the source. This plume can carry substantial energy. To dissipate this energy, we rely on nitrogen injection in the beamline. The fact that nitrogen is molecular (hence radiates efficiently in the IR) and is electronegative, removes both energy and electrons from this plume and efficiently shields downstream structures. However nitrogen diffusing upstream into the source discharge can cause the source plasma to become less stable.

The high ionization energy of helium, and the low mass of the helium ion (both compared to xenon) imply that when mixed with the source xenon it should not participate (to zero order) in the z-pinch electrodynamics. Therefore by injecting helium into the source, the total flow rate might be increased (compared to pure xenon operation) to assist in maintaining xenon purity.

In addition to this idea, we plan to investigate whether a dual-gas injection system will increase the EQ-10 source brightness and/or power. This idea relies on injecting Xenon directly into the bore, while supporting the plasma return loops (which in the EQ-10 play the role of the electrodes) with an argon plasma.

We are planning a series of experiments to explore these concepts. We will present those plans, and our earlier data on Xe/He mixed gas in the EQ-10.

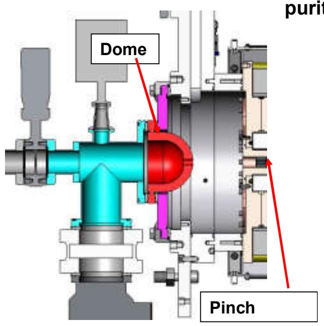


Motivation – why add Helium?

- In the bulk plasma --
  - Helium ionization potential – 24.6ev
  - Xenon ionization potential – 12.13 (1), 21.2 (2)
  - In a Xenon plasma that is not completely ionized, He will remain as a neutral atom.
- In the pinched plasma
  - Te ~ 25 eV
  - Helium will ionize, participate in the pinch.
  - But He mass = 4. Xe mass = 131.

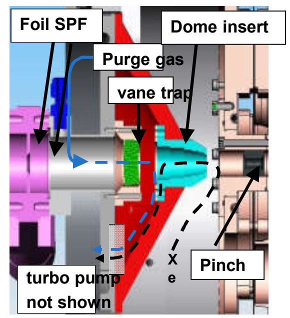
So Helium shouldn't do anything. What's the point?

Low-etendue beamline – little interaction between pinch plasma and beamline. No purge gas required.



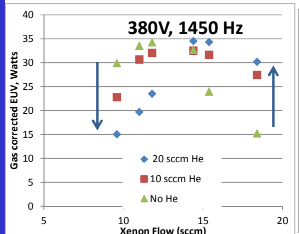
Large etendue beamline. Source plasma interacts with beamline; requires purge gas injection. Purge gas can enter source, affecting stability.

Additional He flow maintains gas purity in source.



Re-analysis of 2010 data

- Early experiments- added He to Xe hoping for more power. . Didn't see improvement – so dropped. Reanalyze that data…

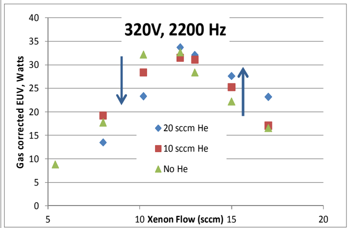


Peak powers nearly identical but peak shifts to higher Xe flow as He is added.

At low Xe flow, power is depressed with He.

At high Xe flow, power is increased with He.

Effect most obvious at lower pulse rate.

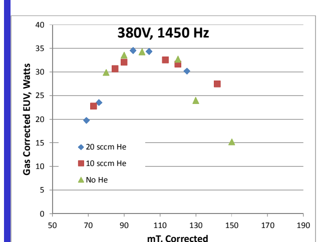


Basic features –

If Xe flow is too low, dilution reduces power. If too high, He increases power.

Consistent with results of varying Xe with no He.

Conclusions from Re-analysis..



Estimate partial pressure of Xe and replot.

Power near peak is identical for all conditions, with total flow (Xe + He) varying from ~10 sccm to ~35 sccm – 3:1 ratio.

New experiments (planned) – how far can we push this? References imply 15% Xe is sufficient - ~ 6:1

Key question does the higher flow really result in improved gas purity? Stay tuned…

New Topic -- Fueling the pinch - Background

- In the EQ-10, gas is injected into the main plasma chamber at a low flow rate, and low pumping rate, to maintain ~ 100 mT in the chamber. (There must be at least sufficient density to support the plasma loops.)
- Since the pinch is fueled not by pressure but by density, the average gas temperature in the chamber has a profound effect on fueling.
- As the power delivered to the pinch is increased, the average temperature increases, reducing the fueling density. EUV output power drops.
- To compensate, Xe flow to the chamber is increased, raising the pressure, hence the density. EUV output power increases.
- But at some point, the increased EUV attenuation caused by the increased Xe density in the beam path, overwhelms the additional EUV power produced by more pinch fueling. EUV output drops.
- To break the connection between fueling (good) and attenuation (bad) try to fuel the pinch directly.
- Once that decision is made – why not fuel the plasma loops with Argon?

Why argon?

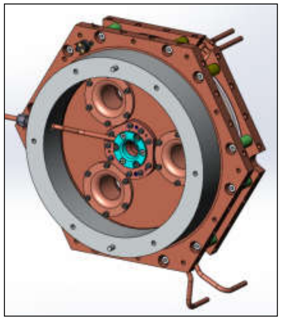
- The gas in the source serves two functions
  - Radiates in EUV (Xenon.)
  - Carries plasma current. (Anything conductive will work.)
- Argon works fine electrically but doesn't make EUV.
- So run an argon plasma, and inject xenon only where we want it.
- Issue -- Gas mixing. If the gases mix perfectly there's probably no advantage.

  How estimate gas mixing? A single pulse will mix the gases. Can we fuel between pulses?

  Quick estimate – assume molecular flow; thermal velocity of Xe at 300K = 20 cm/msec

  At 2 kHz, we get a 10 cm radius cloud of Xe. Extreme upper bound. Seems ok.

  - (wrong in many ways… mean free path is about 1 mm. Crude diffusion estimate yields a much smaller cloud. That's OK, even preferable..



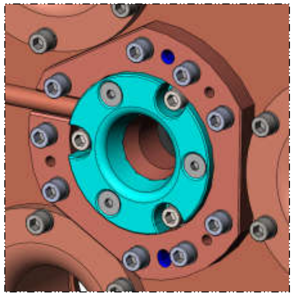
- PoP experiment ..

Add a gas feed directly into the bore. Modify the bore carrier . Fuel there with Xe.

Feed Ar into the chamber

If results are positive, engineer a real gas feed, integrated into the copper plates.

Experiments planned Fall 2018…



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